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Improving Ventilator-Associated Event Surveillance in the National Healthcare Safety Network and Addressing Knowledge Gaps: Update and Review

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Abstract

Purpose of review—The Centers for Disease Control and Prevention (CDC) recently transitioned from ventilator-associated pneumonia surveillance to ventilator-associated event (VAE) surveillance in adult inpatient settings. Since the transition, several modifications have been made to improve surveillance methods, and there is a growing body of data regarding the epidemiology, risk factors, and preventability of VAEs.

Recent findings—The VAE surveillance definition algorithm is based on objective criteria and includes three tiers: Ventilator-Associated Conditions, Infection-related Ventilator-Associated Complications, and Possible and Probable VAP. VAE surveillance expands the purview of surveillance beyond pneumonia alone to include additional complications of mechanical ventilation. Most VAEs are caused by pneumonia, pulmonary edema, atelectasis, and/or acute respiratory distress syndrome. VAEs are associated with adverse outcomes including prolonged mechanical ventilation, longer intensive care and hospital lengths-of-stay, and higher mortality rates. Studies to date suggest that minimizing sedation and optimizing fluid management can reduce VAE rates.

Summary—We review CDC's recent updates on VAE surveillance definitions, methods, and tools, and provide an overview of the growing evidence base for VAE as a patient safety measure. Further work is needed to affirm and extend current knowledge about how best to prevent VAEs.

Keywords

pneumonia; ventilator-associated; mechanical ventilator; critical care; public health surveillance

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Conflict of interest

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Introduction

Ventilator-associated pneumonia (VAP) is a common and morbid complication of mechanical ventilation.[1] Tracking VAP at the national level has proved challenging due to the lack of valid, reliable definitions. The Centers for Disease Control and Prevention (CDC) convened a working group of critical care and healthcare epidemiology experts in 2011 to help develop a new approach to surveillance in mechanically ventilated patients. This new approach, called “Ventilator-Associated Event” (VAE) surveillance, was implemented in CDC’s national healthcare-associated infection surveillance system, the National Healthcare Safety Network (NHSN), in January 2013.[2]

VAE surveillance definitions were developed to increase the reliability of surveillance data, reduce the burden of surveillance in healthcare facilities, and enhance the utility of surveillance data for improving patient safety.[2, 3] The definitions are based on objective criteria, and detect a broad range of clinical events, including VAP.[4, 5] There are three VAE tiers (Figure). The first and foundational definition specified in the algorithm is “Ventilator-Associated Condition” (VAC). Criteria for this condition are met when a patient experiences 2-days of worsening oxygenation following 2-days of stability on a ventilator, defined by changes in the daily minimum fraction of inspired oxygen (FiO₂) or positive end-expiratory pressure (PEEP). The second definition, “Infection-related Ventilator-Associated Complication” (IVAC), is defined by VAC plus an abnormal temperature or white blood cell count; and the start of a new antimicrobial agent continued for 4 days. The third definition tier consists of “Possible VAP” and “Probable VAP,” and is defined by IVAC plus laboratory and/or microbiological evidence of infection.[6]

Since the inception of VAE surveillance in the NHSN, additional studies have been published confirming the limitations of traditional VAP definitions for public reporting and the consequent need for a more objective approach to surveillance.[7–9] In addition, users have sent feedback to CDC regarding operational challenges with the VAE definitions and surveillance methods. Based on this feedback and input from the expert working group that helped develop the VAE definitions, CDC implemented modifications to address the most significant of these challenges. Finally, multiple investigators in the United States and other countries have undertaken studies to address VAE knowledge gaps, including the correlation of VAE with traditional VAP surveillance, clinical correlates of VAE surveillance events, risk factors for VAEs, and strategies to prevent VAEs. This article provides an update and rationale for recent changes to VAE surveillance and reviews the current published literature on VAE.

Patients eligible for inclusion in VAE surveillance

When VAE surveillance was implemented in the NHSN, surveillance was restricted to adult patients (age ≥ 18 years). This restriction was instituted because data were lacking on use of streamlined, objective VAE or VAP definitions in pediatric populations. However, because other surveillance in the NHSN’s “Device-Associated Module” is based on healthcare facility locations rather than on patient age or other patient-level characteristics, VAE’s

patient age restriction created logistical challenges for users. For example, in some cases mechanically ventilated pediatric patients may be cared for in adult intensive care units. According to the original VAE surveillance protocol, these patients were excluded from VAE surveillance, although they were included in counts of ventilator and patient days. CDC therefore decided to eliminate the patient-level age restriction and make VAE surveillance location-based, restricted to adult inpatient locations only, starting in 2014.[10]

Ventilator settings used in meeting the VAC definition

Some users of the NHSN's VAE surveillance protocol in 2013 reported that differences in providers' preferred mechanical ventilation management strategies were triggering some VAEs. These VAEs were typically detected due to changes in PEEP settings occurring in the 0–5 cm H₂O range: for example, a patient may have been on PEEP of 0 cm H₂O for a period of days based on the management preferences of one provider, and then be placed on a PEEP setting of 5 cm H₂O for a period of additional days due to transition of care to a new provider with a preference for maintaining all patients on some degree of PEEP. The change in provider and consequent increase in PEEP would then result in a VAC. To minimize these occurrences, CDC implemented a protocol modification in August 2013 to specify that for surveillance purposes, PEEP settings of 0–5 cm H₂O would be considered equivalent (i.e., the daily minimum PEEP setting would be considered to be 5 cm H₂O for any day where the lowest PEEP settings ranged between 0 and 5 cm H₂O).[6, 11] As a consequence of this modification, daily minimum PEEP settings must now rise to 8 cm H₂O for 2 days to trigger a VAC.

CDC also responded to concerns that VAE detection might vary when using minute-by-minute or hour-by-hour ventilator settings electronically extracted from ventilators rather than manually documented settings charted by respiratory therapists and / or nurses. Researchers in the Netherlands have provided some support for this concern.[12] They retrospectively compared VAE detection in 2 ICUs using daily minimum PEEPs and FiO₂s derived from minute-by-minute electronic ventilator extracts versus hourly values charted by clinicians. They found that the two methods detected a similar absolute number of VACs but only about 75% of the events were common to both methods. Consequently, the revised 2014 protocol now defines the daily minimum setting to be “the lowest setting of PEEP or FiO₂ during a calendar day that is maintained for at least 1 hour.”[6, 10] This new rule might also obviate the concern that some hospitals could “game” VAE definitions by dropping the PEEP and FiO₂ to minimal levels for a minute per day. Under the original VAE rules, this clinically meaningless manipulation of ventilator values would keep patients' daily minimum PEEPs and FiO₂s static and thereby prevent any VAEs from being detected.

Antimicrobial agents eligible for meeting the IVAC definition

The definition for IVAC, like that for VAC, was not developed for detection of respiratory tract infections specifically but was intended to capture a broad range of potentially infectious conditions associated with a deterioration in respiratory status.[2] The initial list of eligible antimicrobial agents was therefore broad. It included drugs such as daptomycin and fidaxomicin that are not used to treat respiratory infections and numerous oral agents

that would typically not be used to treat respiratory infections in mechanically-ventilated patients. The inclusion of such drugs caused confusion among NHSN users, and therefore, with input from the expert working group, CDC removed drugs that are typically not used to treat respiratory infections from the list of eligible agents.[6, 10]

Defining purulent respiratory secretions to meet the Possible and Probable VAP definitions

To meet the Possible or Probable VAP definitions, laboratory and/or microbiological evidence of infection is required. For Possible VAP, patients must have purulent respiratory secretions (defined as ≥ 25 white blood cells and ≥ 10 epithelial cells per low power field on Gram stain) or a positive culture of respiratory secretions. For Probable VAP, patients must have purulent secretions plus a positive culture of respiratory secretions (meeting or exceeding specified growth thresholds). There are other criteria for *Legionella* and selected respiratory viruses as well as criteria for lung histopathology to satisfy the Probable VAP definition, but these are infrequently used.

Some hospitals noted that they were unable to use the purulent respiratory secretions criterion as originally specified because their clinical laboratories do not routinely report epithelial cell counts or because of other variations in laboratory practices. CDC consequently modified the VAE surveillance protocol to provide additional flexibility within this criterion.[6, 10]

Electronic tools for surveillance

For new users in particular, the VAE algorithm can seem complex and confusing. To help users learn the definitions, CDC developed a web-based “VAE Calculator.”[13] The Calculator, which was updated recently to reflect the 2014 protocol modifications, allows users to enter VAE data elements for a single patient and receive a VAE determination along with an explanation regarding why the determination was made. Patient identifiers are not entered into the Calculator; it is primarily intended to be an educational tool, and does not store patient data or submit data to the NHSN.

One of CDC’s goals is to help healthcare facilities automate VAE detection. CDC has embarked on two initiatives to facilitate this goal: development of a web service approach and creation of a synthetic patient dataset. The web service, which is currently in a limited pilot implementation, allows an Electronic Health Record (EHR) system or a local infection surveillance system to submit de-identified data from a population of patients to a centralized server. The server receives the data and applies the VAE definitions, returning to the sender a list of all the patient records meeting the various VAE criteria. The sender maintains a linkage between the patient records submitted and the actual patient information, insuring that no Personally Identifiable Information leaves the sender’s site.

The web service may be used in two ways. Electronic systems may utilize the service by making routine calls to the web service for case determinations. This obviates the need to code for VAE definitions within EHRs or infection surveillance software. The web service

can also be used as a development and validation tool by vendors that prefer to code for VAE detection themselves rather than calling on the web service. Developers that opt for this pathway may validate their coding by submitting test data to the web service. This is important to ensure consistency and accuracy between different VAE implementations. Errors that occur in this coding process may lead to systematic inaccuracies. The web service provides a single source of truth for developers to test themselves against. As a complement to the web service, CDC is working to create a synthetic patient dataset that vendors can use to test their VAE coding. The dataset is anticipated to be available in 2015.

CDC is working with partners to develop Clinical Document Architecture messages to enable facilities to electronically report VAEs to the NHSN. At present, users need to manually enter VAEs into the NHSN web-based portal. Once the Implementation Guide is ready, EHR developers and proprietors of commercial infection control surveillance software will be able to submit events electronically and automatically.

Addressing VAE knowledge gaps: recent additions to the scientific literature

Recent studies have deepened our knowledge of VAE epidemiology, morbidity, risk factors, and potential prevention strategies. Klompas and colleagues characterized the incidence, microbiology, and attributable morbidity of VAEs amongst 20,356 consecutive episodes of mechanical ventilation in a large academic center.[14] VAEs were detected in 5.6% of episodes. Of these, 38% met criteria for IVAC, 12% met criteria for Possible VAP, and 11% met criteria for Probable VAP. The risk for VAC was highest in medical, surgical, and thoracic units; the risk was lowest in cardiac and neuroscience units. The most frequently isolated organisms in patients with Possible or Probable VAP were *Staphylococcus aureus* (29%), *Pseudomonas aeruginosa* (14%), and *Enterobacter* species (7.9%). All VAE tiers were associated with prolongation of mechanical ventilation and hospital length of stay as well as higher hospital mortality risk compared to matched patients without VAEs. IVAC was associated with longer durations of mechanical ventilation and hospital lengths-of-stay compared to VAC alone but there was no difference in mortality risk between tiers.

Dutch investigators affirmed that VAC surveillance detects a different population of patients than traditional VAP surveillance.[12] They retrospectively applied VAE definitions to a cohort of patients and compared them to VAPs that were prospectively identified by research nurses using classical clinical, radiographic, and microbiologic criteria. The Dutch investigators found limited overlap between VAC and VAP. Only 44% of patients with clinical VAP met VAC criteria and only 9% of patients with VAC met clinical criteria for VAP. The investigators analyzed why patients with VAP did not meet VAC criteria. The most common reason (76% of VAC-negative cases) was because VAP patients' ventilator settings did not increase despite their ostensible pulmonary infections.

The Dutch team also reviewed the charts of 81 patients with VAC to identify possible clinical etiologies for these patients' respiratory deterioration. They found that 40/81 (50%) events were associated with respiratory tract infections, mucous plugging, and/or aspiration; 39/81 (48%) cases were associated with volume overload, heart failure, and/or pleural

effusion; and 30/81(37%) cases were associated with sepsis, pneumothorax, abdominal distension, or acute neurological events. There was no apparent etiology for VAC in 10/81 (12%) cases. These findings mirror the results of previous investigations.[4, 5]

Investigators in four studies have found relatively limited overlap between VAC and clinically-defined VAP.[4, 12, 15, 16] Most VACs are attributable to pneumonia, pulmonary edema, atelectasis, and/or acute respiratory distress syndrome.[4, 5, 12] This implies that preventing VAEs will require broadening ventilator bundles to include interventions that target all of these conditions. Fortunately, the interventions needed to prevent these conditions are congruent with many of the emerging best practices endorsed by critical care societies such as daily spontaneous awakening and breathing trials, maintaining euvolemia, minimizing blood transfusions, ventilating patients with low tidal volumes, and encouraging early mobility.[17] VAE surveillance therefore offers intensivists a metric to monitor the impact of these best practices and a means to motivate care teams to optimize their performance. [3] [18]

Investigators are now working to confirm that these best practices can indeed prevent VAEs. Lewis and colleagues organized a case-control study to identify risk factors associated with VAC and IVAC.[19] They matched 110 patients with VAC to 110 patients without VAC. Of the 110 patients with VAC, 38 met criteria for IVAC. They then evaluated a host of potentially modifiable care factors including head of bed elevation, oral care with chlorhexidine, mode of mechanical ventilation, tidal volume, frequency of spontaneous awakening and breathing trials, net daily fluid balance, use of blood products, choice of sedatives, and route of nutrition. They found that mandatory modes of mechanical ventilation and positive fluid balances were risk factors for VAC and early administration of benzodiazepines was a risk factor for IVAC. These findings support the importance of sedation, fluid management, and ventilator settings in the design of bundles to prevent VAEs.

Emerging studies on VAE prevention highlight the importance of minimizing sedation and optimizing fluid balance. We are aware of at least 3 studies evaluating the preventability of VAEs. The first study was published by the Canadian Critical Care Trials Group.[15] They retrospectively evaluated VAC rates and risk factors for VAC amongst 1330 patients sampled intermittently from 11 ICUs enrolled in a two-year prospective effort to increase adoption of best practices for the care of ventilated patients. Over the study period, there was a modest increase in the performance of recommended measures and a corresponding modest decrease in the risk of VAC. On multivariable regression, the percentage of days with spontaneous awakening trials was associated with lower VAC risk (OR 0.93 per 1% increase in percent of days with spontaneous awakening trials, 95% CI 0.87–1.00).

The second study assessed the impact of enhanced fluid management on VAP and VAC risk. Dessap and colleagues retrospectively applied VAC definitions to data from a prospective randomized trial of the benefit of daily B-type Natriuretic Peptide (BNP) levels to guide fluid management during weaning from mechanical ventilation.[16] They found that daily BNP measurements were associated with more negative fluid balances, fewer days of mechanical ventilation, and significant decreases in both VAC (approximately 52% fewer

VACs in the intervention group as compared to the usual care group, $p=0.02$) and VAP (approximately 48% fewer VAPs in the intervention group, $p=0.03$).

The third study of VAE prevention is the CDC Prevention Epicenters Wake Up and Breathe Study. This is a prospective multicenter evaluation of the benefit of paired daily spontaneous awakening and spontaneous breathing trials on the impact of VAEs (ClinicalTrials.gov Identifier NCT 01583413). Results from this study are expected later this year.

Conclusion

The introduction of VAE surveillance in the NHSN in 2013 was followed by refinements and clarifications to the VAE protocol in response to user feedback. CDC also introduced an expanding suite of electronic tools to help providers and hospitals implement VAE surveillance. Recent investigations have confirmed the strong association between VAEs and adverse outcomes and are starting to provide data on how best to prevent VAEs.

VAE prevention begins with recognition that there is limited overlap between VAC and VAP. Most VACs are triggered by one or more of four conditions: pneumonia, pulmonary edema, atelectasis, and / or acute respiratory distress syndrome. Minimizing patient sedation and optimizing fluid management both appear to be potent strategies to prevent VACs. Additional work to define and implement bundles optimized to prevent VAEs holds further promise to improve outcomes for mechanically ventilated patients.

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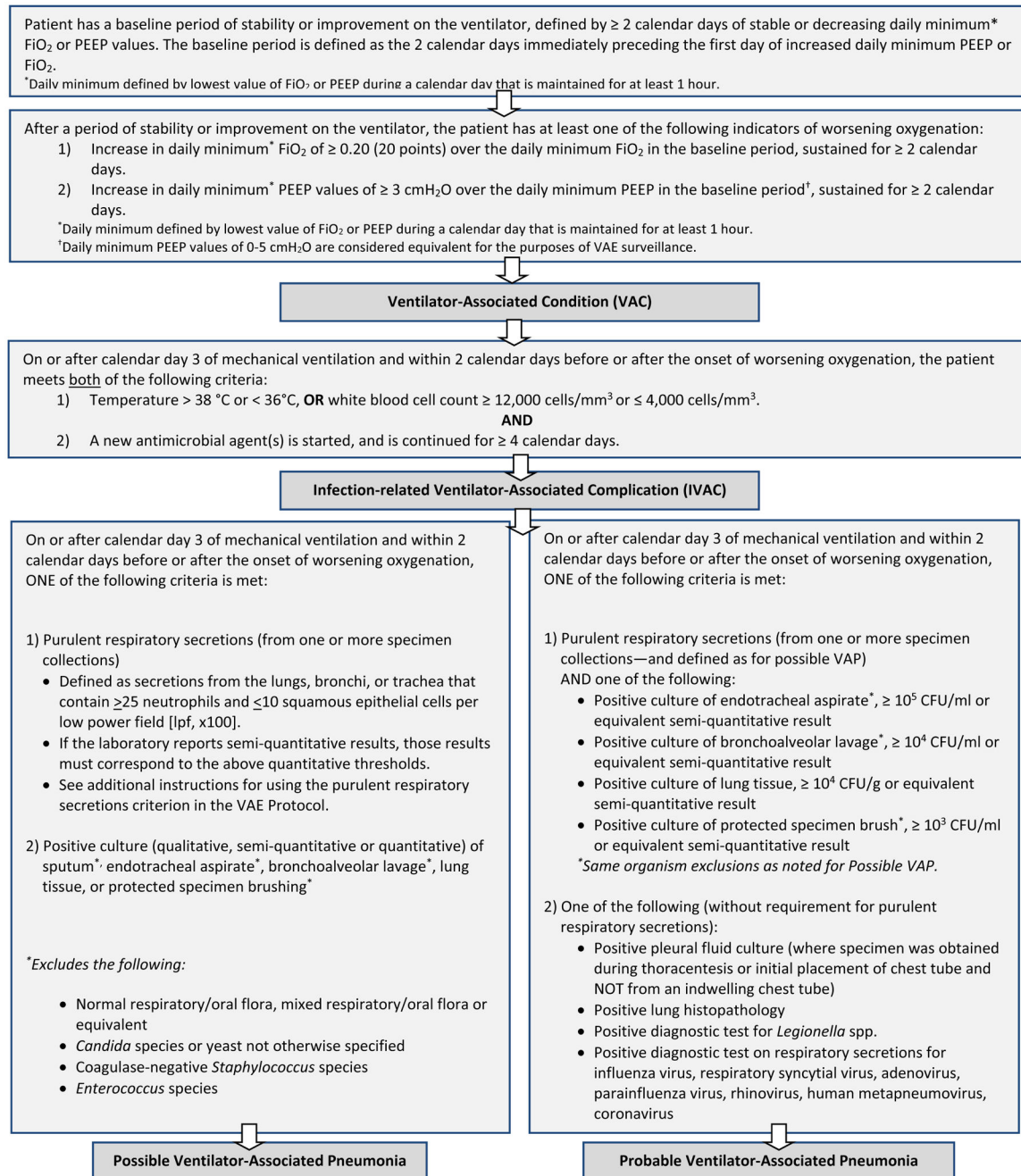
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Key points

- Surveillance for ventilator-associated events (VAE) was implemented in CDC's National Healthcare Safety Network in January 2013; improvements and clarifications to the surveillance protocol have recently been made.
- CDC continues to work on developing electronic tools to assist NHSN users in conducting VAE surveillance.
- Studies have shown that VAEs are strongly associated with adverse outcomes.
- Recent additions to the VAE scientific literature are beginning to address important knowledge gaps, including the extent to which VAEs are preventable.

**Figure.**

Heading: Ventilator-associated event surveillance definition algorithm

Legend: None

Source: Centers for Disease Control and Prevention. Ventilator-Associated Event Protocol.

Available at: <http://www.cdc.gov/nhsn/acute-care-hospital/vae/index.html>. Accessed March 25, 2014.